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LONGEVITY OF ONION SEED IN RELATION TO STORAGE CONDITIONS

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STATEMENT OF THE PROBLEM

It is generally known that onion seed is one of the shortest-lived of the seeds of any of the common vegetable crops. It is more or less axiomatic among growers that high germination and good stands cannot be expected from onion seed that is more than a year old. Commercial growers will not knowingly plant seed more than a year old if seed of the immediately preceding seed crop is obtainable. Thus, following a year of a short seed crop of particular varieties, insufficient supplies are available, there is no carry-over worth depending on, and prices are very high. Turning to poorly adapted varieties of which there are good supplies of seed may be of no value. The question has often been raised as to how such a situation could be avoided, but up to the present time there has been no change in handling or production practices in the desired direction, in part because the practicability of long-time storage has not been sufficiently demonstrated.

In some of the principal areas of the United States where onions are grown for market and where onion plants are grown for sale for planting elsewhere, climatic conditions are such that onion seed is especially short-lived. For example, in certain localities in southern Texas near the Gulf of Mexico, where humidity and temperature are both high, the germinability and viability of onion seed often decrease appreciably in the short time between receipt of a shipment of seed and the planting of the seed. In case of much delay in normal time of planting or the necessity of replanting the plant beds, rather serious losses may accrue in a very few weeks.

[1] Experimental work by senior author; statistical analysis and preparation of manuscript by junior author.

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A large proportion of the seed of the Bermuda and Spanish types of onion is obtained from foreign sources, such as the Canary Islands. Much of the seed imported from such sources is shipped in large sealed tin cans to delay deterioration. Even so, there is still much improvement to be made in commercially practicable methods of handling onion seed so as to preserve its viability for longer periods of time.

EARLIER INVESTIGATIONS

No attempt will be made here to review the rather extensive literature that has been developed with reference to longevity of seeds. Only a few studies will be cited that have some special bearing on the present work.

Duvel (*1*)[2] showed that seeds of numerous vegetable crops retained a high germinability and viability for a longer time in cool, northern locations (Michigan) than on the Gulf coast in Alabama, where both temperature and humidity are high. His studies of effects of moisture and temperature extended over periods of but a few months and so will not be reviewed in relation to this long-time storage problem.

Simpson (*5*) studied the effect of different storage and seed conditions on the longevity of sea-island cottonseed at James Island, S. C., where humidity and temperature are high. Cottonseed is usually considered as fairly long-lived; however, seed stored in a frame building and with a moisture content of 10 percent or higher deteriorated seriously in 2 years and was dead in 4 whether or not it was placed in sealed containers. Seed, dried down to 7.8-percent moisture before being placed in storage, kept without significant loss of germinating power for 4½ years if kept in tin cans with airtight or nonairtight lids. Similar sun-dried seed stored in bags with free access to the air soon developed a moisture content of 10 to 11 percent and thereupon deteriorated like the other seed of 10-percent moisture content or higher. Seed stored with a moisture content of 8 to 9 percent showed no appreciable loss of viability after 4½ years.

A study by San Pedro (*4*) in the Philippine Islands, reported in 1936, was planned more nearly like the present study than any other noted in the literature. Several crops were included, among them cabbage, carrot, lettuce, radish, parsley, bean, tomato, and eggplant. The seeds were stored in paper packets in sealed glass jars, both with and without calcium chloride in the jars as a drying agent, at temperatures of 0°, 10° to 13°, 20° to 22°, and 27.5° to 28° C., and samples were withdrawn for germination tests after approximately 5½, 7, 9, 11, 15, and 20 months. Germination was in Petri dishes on moist filter paper. Some of the principal results follow.

When seeds were stored over calcium chloride and thus kept dry, there was no marked effect of temperature at the 5½-month germination; after 11 months they showed some deterioration at all temperatures, especially at 10° to 13° C. or higher. Stored without calcium chloride, all those named above showed appreciable deterioration, some serious, even at 0°, whereas at 20° to 22° they were practically all dead. San Pedro concluded that moisture is more important than temperature, but no moisture determinations were made to indicate what percentage is critical. It seems probable that considerable incipient damage may have occurred as a result of the seeds absorb-

[2] Italic numbers in parentheses refer to Literature Cited, p. 22.

ing a relatively great amount of atmospheric moisture in the tropical climate before the experiments were set up. Sealing in a high [unknown] moisture content of the seeds was harmful even at 0° C.

Steinbauer and Steinbauer (*7*) worked with the seed of the American elm, of particular interest here because it is very short-lived under natural conditions. Seeds were stored at constant temperatures of 0°, 10°, and 20° C. in a variety of conditions. Those exposed freely to the air at all three temperatures were all dead within 13 months of collection of the seed. Those sealed without previous artificial desiccation of air-dry seed were likewise all dead. Those lots subjected to drying over 50-, 75-, and 95-percent sulphuric acid and sealed before storage retained their viability better than those desiccated over 25-percent sulphuric acid or not desiccated, but the differences were small, except at 20°. Desiccation was of little value for seed stored at 0°, but at 20°, after 9 months, the driest seeds germinated 44 percent, while the nondried germinated 2 to 13 percent. After 13 months the desiccated seed at 20° germinated but 1 to 2 percent, and those stored at 0°, 3 to 6 percent. The original germination of the seed was about 70 percent.

Joseph (*3*) conducted storage studies with seed of the parsnip, another species with a notoriously short-lived seed. Of particular interest in relation to the present investigations were her observations on the effects of two storage temperatures—approximately 25° and 5° C.—and of artificially drying the seeds at temperatures of 70° to 90° for periods of a few hours before storing in tightly corked bottles. Air-dry ripe seeds contained about 6 percent of moisture and lost nearly half of their original germinating power in 2 years at both temperatures. There were considerable differences in retention of viability among several stocks of seeds used, some of them being dead, others with a fair germination at the end of 3 years. Different stocks reacted differently to temperature, with the result that no definite conclusions were justified regarding the effect of storage temperature on air-dry seeds.

The tolerance of air-dried parsnip seed to high temperature in a ventilated or vacuum oven was a little surprising. Seeds well exposed to drying were reduced to moisture contents of approximately 0.4 to 1.7 percent at temperatures of 70° to 90° C.; 4½ hours at 87.5° caused no decrease in percentage of germination as determined on filter paper in the laboratory. It was not shown whether such treatment lowered vitality so as to affect stand of seedlings under the more rigorous conditions of soil-germination tests. Seeds so dried, then stored in tightly corked bottles, showed a variable loss of germinability in 3 years ranging from 0 to 37.5 percent. In these lots the losses in germination of seed stored at 5° were about half as great as in those stored at 25°.

Unfortunately, the several treatments reported by Joseph (*3*) were not all made on the same stock and differences in response were shown among stocks for a single treatment. Within the series of dehydrated samples (0.4 to 1.7 percent moisture) there was no apparent correlation of germination and moisture content of seed. While certain of the dehydrated seed lots retained viability better than the air-dry samples of the same stock, there were again differences among stocks and a lack of comparable tests, preventing an accurate evalua-

tion of the effects of either moisture content or temperature. In general, however, artificial drying seemed beneficial.

MATERIALS AND METHODS

SEED

In the fall of 1929 a few pounds each of seed of Red Bermuda and Yellow Bermuda varieties of onion were obtained from the Canary Islands, Yellow Globe from Indiana, and Valencia from Spain, from growers believed to have stocks of good quality. All lots were of seed harvested in the summer of 1929. The moisture contents of these four lots as received were low, ranging from 7 to 8 percent. Germination tests were made by the seed laboratory of the Bureau of Plant Industry in December 1929, and the percentage germination of the seed was found to be as follows: Red Bermuda, 91.0; Yellow Bermuda, 71.0; Yellow Globe, 92.5; and Valencia, 88.5.

PREPARATION OF SEED FOR STORAGE

Seeds of all varieties were to be stored at room temperature at Washington, D. C., and at 40° and 20° F. in the cold-storage laboratory of the Division of Fruit and Vegetable Crops and Diseases at Arlington Experiment Farm, Arlington, Va. Separate lots of seed of each variety were adjusted to moisture contents of approximately 6, 8, and 10 percent for storage at each temperature, and each of the "moisture lots" was again divided into two groups, to be hermetically sealed or left unsealed.

In preparing the seed to be stored, weighed quantities were spread thinly in shallow pans and placed in a large laboratory oven through which a strong current of air was forced at a temperature of 85° to 95° F. The seeds were stirred and weighed frequently until each lot had reached a predetermined weight representative of 6-percent moisture for that lot. Upon reaching this moisture content the seed was removed from the oven and placed in an airtight container until the preparations for storing were completed 2 or 3 days later.

The seeds with adjusted moisture contents destined for the several storage conditions were placed in 15 by 150 mm test tubes, 10 g of seed per tube. A sufficient number of tubes of seed of each variety, moisture content, and exposure (sealed and not sealed) were prepared to furnish a tube of each ultimate lot for each germination test to be made over a period of several years. Thus no container of seed needed to be opened or the seeds disturbed in any way during the prolonged storage period.

The adjustment of moisture content of the seeds was accomplished as follows: Ten g of carefully weighed, dried seed was placed in the tube; then a piece of filter paper about 2 by 5 cm in size was inserted into the tube. To the filter paper in the tubes of those lots of seed to be raised to 8-percent moisture content, 0.2 ml of distilled water was applied from a burette, and to those to be raised to 10-percent moisture, 0.4 ml was added. Precautions were taken to prevent any liquid water touching the seeds or the interior surface of the tube. The water was distributed over the paper as much as possible, and the tubes were immediately closed. Sealed lots were tightly corked and the nonsealed lots closed with cotton plugs. All tubes were kept in an upright posi-

tion until the following day to prevent the seeds from touching the wet filter paper. The corks and rims of the sealed tubes were then thoroughly covered with a generous application of sealing wax, and all lots were placed in the respective storage places in loosely closed corrugated paper cartons.

The 0.2-ml and 0.4-ml additions of water to the 8- and 10-percent moisture lots resulted in only approximately that moisture content of the seed. If all the added water were absorbed by the seeds, the moisture contents would have become 8.5 and 10.6 percent, respectively. Part of the water, however, was doubtless retained by the filter paper or absorbed by the cork, and part of it remained as vapor in the atmosphere of the tube. Furthermore, these original moisture contents could hardly be expected to remain constant in either the nonsealed or sealed containers. In the former, the seeds would tend to reach equilibrium with the atmospheric moisture of the respective storage rooms; and in the latter, water of respiration might be expected to accumulate. Unfortunately, moisture determinations were not made on the several lots of each germination test during the several years.

STORAGE CONDITIONS

The "room" temperature varied from 70° F. in winter to 85° or 90° in summer, and was occasionally higher for short periods. The use of corrugated-fiber cartons doubtless resulted in some lag and smoothing out of extreme fluctuations. Relative humidity varied widely, but the climate of Washington, D. C., is typically humid.

The temperatures of 40° and 20° F. storage rooms were controlled within ±2°. The prevailing relative humidities in these two rooms were approximately 85 and 25 percent with vapor pressures of approximately 0.21 and 0.025 inch of water, respectively. The seeds were placed under the different storage conditions in December 1929.

GERMINATION TESTS

Seeds were withdrawn from storage for germination tests in the spring of 1930, 1932, 1933, 1934, and 1936. Certain lots are still in storage for tests in later years.

One tube of seed was withdrawn from each variety, temperature, moisture, and exposure a few days before the seeds were to be planted. Four lots of 100 seed each were counted from each tube; each lot was placed in a small vial which was then labeled and closed with a cork-lined screw cap until the seed could be planted.

The seeds were sown in greenhouse flats 16 inches wide, 24 inches long, and 2½ inches deep, containing muck soil from the Kankakee area in Indiana. In 1930 the soil was not sterilized prior to planting and serious losses from damping-off occurred. In subsequent tests the soil was partially sterilized with steam 2 to 3 weeks before planting in an effort to avoid loss from damping-off of germinating seeds or of seedlings. One hundred seeds were sown in each of 12 rows, one-fourth inch deep, across each flat. The quadruplicate sowings of the numerous seed lots were made in four different flats (except in 1934 when they were made in only two flats) and the twenty-odd flats were distributed more or less at random over the greenhouse benches. Germination counts were made 10 days to 2 weeks after planting.

ANALYSIS OF DATA

The germination data have been tabulated and analyzed by Snedecor's (*6*) adaptation of Fisher's (*2*) method of analysis of variance. Unfortunately, sufficient lots of seed at 6-percent moisture were prepared for only 4 years' tests, although ample material was prepared for several more tests of the 8- and 10-percent moisture lots. Thus, an analysis for all three moisture conditions can be made for data including only the 1930 to 1933 observations. A separate analysis has been worked out for the 8- and 10-percent moisture lots extending through 1936.

When this work was planned it seemed particularly important to obtain accurate comparisons between moisture contents and sealed versus unsealed seeds. Previous work suggested that relatively large differences might exist between different temperatures and between stocks or varieties. Variance due to stocks or varieties was considered secondary in importance to that due to sealing and moisture; hence, the flats within a replication were grouped in more or less solid blocks by varieties, bringing the several moisture, temperature, and sealing lots of one variety in relatively close proximity to each other to insure their being under the most uniform conditions possible during the germination tests. Thus, from this point of view the variety groups might be considered as subreplications within a single large replicate area or block. This may not have been the ideal distribution from the standpoint of obtaining maximum accuracy in determining variance due to variety or stock, but there appears to be an advantage in this particular instance because of the factors in which there was special interest. After all, when it is recalled that only 100 to 125 square feet of bench space was occupied by the germination flats each year, and that the analyses cover 3 or 5 years, the matter of position of individual flats would seem to involve no serious question.

PRESENTATION OF RESULTS

GENERAL CONSIDERATIONS

The percentage germination recorded on the basis of emergence of seedlings from soil under commercial conditions will generally be lower than percentages recorded on the same lots of seed by the conventional laboratory-germination methods. Not all seeds that will germinate on moist blotting paper or other suitable medium under ideal, controlled laboratory conditions will produce a sprout of sufficient vigor to emerge from soil, especially if the seed is old. There are several possible factors that prevent emergence of all sprouts of seeds that actually germinate in the soil; also there are frequently adverse conditions in a soil that may interfere with germination as well as with seedling emergence. Thus, from the standpoint of the practical grower, a laboratory test on seed of low vigor but fairly good percentage germination may be a misleading indication of the value of that seed when planted in soil. Even good, strong onion seed that will germinate over 90 percent in the laboratory will almost certainly show less than 90-percent emergence when sown in soil under practical cultural conditions.

In these studies, germinations were made in soil under greenhouse conditions to avoid overrating any storage condition in relation to its preservation of the plant-producing capacity of the seed.

Soil germination (or preferably emergence) tests have their disadvantages. It is sometimes very difficult to avoid adverse conditions that result in such low percentage emergence of really good seed that an unfairly low rating may be given. In the first soil germinations in the present work, a serious infection of damping-off, and possibly other micro-organisms in the soil, resulted in some lots showing a distinctly lower emergence than was observed for the same lots in later years. In such cases the seedlings that did emerge were generally rather badly infected. This hazard was a special disadvantage in this work, because the purpose was to determine the progressive change in germinability from year to year. Even so, it seemed preferable to assume the risk of obtaining germination figures that were sometimes too low than to risk overestimating the value of certain storage conditions in relation to preservation of actual plant-producing power of seed so stored.

In the interests of brevity, emphasis, and clearness, the germination data are presented as a number of tabulations involving either typical detailed portions of the whole or summaries in which varieties have been combined. The analyses of variance were of course made on the total original data for the respective series of years.

Tables 1 and 2 present the means of quadruplicate germinations obtained with a single variety, Red Bermuda, which is more or less typical of all four varieties. Similar tables, including all varieties, would be unwieldy for the reader, and of doubtful superiority here.

TABLE 1.—*Percentage germination of Red Bermuda onion seed in soil after storage for 1 to 4 years under different conditions* [1]

[Laboratory germination December 1929, 91 percent]

SEED STORED IN NONSEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of— Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
6	1930	52.5	78.8	66.5	65.9
	1932	45.5	38.5	43.8	42.6
	1933	45.5	57.8	36.0	46.4
Mean		47.8	58.3	48.8	51.6
8	1930	70.5	67.0	47.5	61.7
	1932	45.5	42.3	35.3	41.0
	1933	31.8	55.0	58.3	48.3
Mean		49.3	54.8	47.0	50.3
10	1930	63.5	72.5	54.0	63.3
	1932	43.8	41.5	28.5	37.9
	1933	29.8	55.5	58.8	48.0
Mean		45.7	56.5	47.1	49.8
Mean	1930	62.2	72.8	56.0	63.6
	1932	44.9	40.8	35.8	40.5
	1933	35.7	56.1	51.0	47.6
Mean		47.6	56.5	47.6	50.6

[1] Difference required for significance between means of quadruplicate observations, 17.1 percent; between means involving 12 observations, 9.9 percent; 36 observations, 5.7 percent; 108 observations, 3.3 percent.

TABLE 1.—*Percentage germination of Red Bermuda onion seed in soil after storage for 1 to 4 years under different conditions*—Continued

SEED STORED IN SEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
6	1930	51.3	71.5	67.5	63.4
	1932	59.0	44.8	45.0	49.6
	1933	57.3	75.8	79.3	70.8
Mean		55.8	64.0	63.9	61.3
8	1930	63.8	82.5	72.8	73.0
	1932	58.5	49.5	39.0	49.0
	1933	41.3	66.0	73.0	60.1
Mean		54.5	66.0	61.6	60.7
10	1930	47.8	78.5	70.3	65.5
	1932	38.3	64.5	43.8	48.9
	1933	7.8	66.8	78.5	51.0
Mean		31.3	69.9	64.2	55.1
Mean	1930	54.3	77.5	70.2	67.3
	1932	51.9	52.9	42.6	49.1
	1933	35.4	69.5	76.9	60.7
Mean		47.2	66.6	63.2	59.0

TABLE 2.—*Percentage germination of Red Bermuda onion seed in soil after storage for 1 to 7 years under different conditions* [1]

[Laboratory germination December 1929, 91 percent]

SEEDS STORED IN NONSEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
8	1930	70.5	67.0	47.5	61.7
	1932	45.5	42.3	35.3	41.0
	1933	31.8	55.0	58.3	48.7
	1934	25.8	53.0	59.5	46.1
	1936	0	54.5	70.5	41.7
Mean		34.7	54.4	54.2	47.8
10	1930	63.5	72.5	54.0	63.3
	1932	43.8	41.5	28.5	37.9
	1933	29.8	55.5	58.8	48.0
	1934	27.3	51.8	54.8	44.6
	1936	0	43.8	68.8	37.5
Mean		32.9	53.0	53.0	46.3
Mean	1930	67.0	69.8	50.8	62.5
	1932	44.6	41.9	31.9	39.5
	1933	30.8	55.3	58.5	48.2
	1934	26.5	52.4	57.1	45.3
	1936	0	49.1	69.6	39.6
Mean		33.8	53.7	53.6	47.0

[1] Difference required for significance between means of quadruplicate observations, 14.9 percent; between means involving 12 observations, 8.6 percent; 20 observations, 6.7 percent; 60 observations, 3.9 percent; 180 observations, 2.2 percent.

TABLE 2.—*Percentage germination of Red Bermuda onion seed in soil after storage for 1 to 7 years under different conditions*—Continued

SEEDS STORED IN SEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
8	1930	63.8	82.5	72.8	73.0
	1932	58.5	49.5	39.0	49.0
	1933	41.3	66.0	73.0	60.3
	1934	40.8	74.0	82.0	65.6
	1936	2.3	88.3	83.5	58.0
Mean		41.3	72.0	70.1	61.2
10	1930	47.8	78.5	70.3	65.5
	1932	38.3	64.5	43.8	48.8
	1933	7.8	66.8	78.5	51.2
	1934	0	67.0	81.8	49.6
	1936	0	74.0	86.0	53.0
Mean		18.8	70.2	71.9	53.6
Mean	1930	55.8	80.5	71.5	69.3
	1932	48.4	57.0	41.4	48.9
	1933	24.5	66.4	75.8	55.7
	1934	20.4	70.5	81.9	57.6
	1936	1.1	81.1	84.3	55.5
Mean		30.0	71.1	71.0	57.4

Tables 3 and 4 show the means of quadruplicate germinations of all four varieties, each value, other than those indicated as means, being the mean of 16 observations. Interactions involving variety cannot be observed within these two tables—nor in tables 1 and 2—and furthermore the whole mass of figures involving either 864 or 960 observations is too complex for readily observing interactions. The interaction variances are of most interest in this particular connection and are shown in the table of analysis of variance.

TABLE 3.—*Percentage germination of 4 stocks of onion seed in soil after storage for 1 to 4 years under different conditions* [1]

[Mean laboratory germination in December 1929, 85.8 percent]

SEED STORED IN NONSEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
6	1930	63.8	68.4	63.1	65.1
	1932	53.4	51.1	40.8	48.4
	1933	57.9	66.9	51.9	58.9
Mean		58.4	62.2	51.9	57.5
8	1930	67.6	70.6	59.9	66.0
	1932	56.1	55.9	45.9	52.6
	1933	52.7	64.4	64.0	60.4
Mean		58.8	63.7	56.6	59.7

[1] Difference required for significance between means of quadruplicate observations on 4 varieties (16 observations), 8.6 percent; between means involving 48 observations, 4.9 percent; 144 observations, 2.9 percent; 432 observations, 1.6 percent.

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TABLE 3.—*Percentage germination of 4 stocks of onion seed in soil after storage for 1 to 4 years under different conditions* —Continued

SEED STORED IN NONSEALED CONTAINERS—Continued

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
10	1930	68.3	63.0	57.4	62.9
	1932	49.7	52.8	33.9	45.5
	1933	44.8	61.8	49.1	51.9
Mean		54.2	59.2	46.8	53.3
Mean	1930	66.6	67.3	60.2	64.7
	1932	53.1	53.3	40.2	48.9
	1933	51.8	64.4	55.0	57.1
Mean		57.1	61.6	51.8	56.9

SEED STORED IN SEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Room	40° F.	20° F.	Mean
6	1930	58.6	71.8	72.1	67.5
	1932	58.6	52.7	56.1	55.8
	1933	68.3	73.7	76.7	72.9
Mean		61.8	66.0	68.3	65.4
8	1930	66.9	78.9	67.4	71.0
	1932	60.0	67.7	53.4	60.4
	1933	52.3	72.3	71.4	65.3
Mean		59.7	73.0	64.1	65.6
10	1930	58.2	73.3	70.1	67.2
	1932	32.6	63.4	56.0	50.8
	1933	7.9	69.8	77.1	51.6
Mean		32.9	68.8	67.8	56.5
Mean	1930	61.2	74.6	69.9	68.6
	1932	50.4	61.3	55.2	55.6
	1933	42.8	71.9	75.1	63.3
Mean		51.5	69.3	66.7	62.5

TABLE 4.—*Percentage germination of 4 stocks of onion seed in soil after storage for 1 to 7 years under different conditions* [1]

[Mean laboratory germination in December 1929, 85.8 percent]

SEEDS STORED IN NONSEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
8	1930	67.6	70.6	59.9	66.0
	1932	56.1	55.9	45.9	52.6
	1933	52.7	64.4	64.0	60.4
	1934	41.4	65.4	64.8	57.2
	1936	0	62.9	68.4	43.8
Mean		43.6	63.9	60.6	56.0

[1] Difference required for significance between means of quadruplicate observations of 4 varieties (16 observations), 7.5 percent; between means involving 32 observations, 5.3 percent; 48 observations, 4.3 percent; 80 observations, 3.3 percent; 160 observations, 2.4 percent; 240 observations, 1.9 percent; 480 observations, 1.4 percent.

TABLE 4.—*Percentage germination of 4 stocks of onion seed in soil after storage for 1 to 7 years under different conditions*—Continued

SEEDS STORED IN NONSEALED CONTAINERS—Continued

Moisture content of seed (percent)	Year germinated	Germination of seed previously stored at temperature of—			
		Room	40° F.	20° F.	Mean
		Percent	*Percent*	*Percent*	*Percent*
10	1930	68.3	63.0	57.4	62.9
	1932	49.7	52.8	33.9	45.5
	1933	44.8	61.8	49.1	51.9
	1934	33.0	63.5	59.3	51.9
	1936	0	56.5	66.7	41.1
Mean		39.1	59.9	53.3	50.8
Mean	1930	68.2	66.8	58.7	63.7
	1932	52.9	54.4	39.9	49.1
	1933	48.7	63.1	56.6	56.1
	1934	37.2	64.5	62.0	54.6
	1936	0	59.7	67.6	42.4
Mean		41.4	61.9	56.7	53.2

SEEDS STORED IN SEALED CONTAINERS

Moisture content of seed (percent)	Year germinated	Room	40° F.	20° F.	Mean
8	1930	66.9	78.9	67.4	71.0
	1932	60.0	67.7	53.4	60.4
	1933	52.3	72.3	71.5	65.3
	1934	59.9	75.6	85.0	73.5
	1936	19.8	80.6	83.9	61.8
Mean		51.8	75.0	72.2	66.3
10	1930	58.2	73.3	70.1	67.2
	1932	32.6	63.7	56.0	50.8
	1933	7.9	69.8	77.1	51.6
	1934	1.4	74.8	83.6	53.3
	1936	0	74.3	81.8	52.0
Mean		20.1	70.9	73.7	54.9
Mean	1930	62.6	76.1	68.8	69.1
	1932	46.3	65.7	54.7	55.6
	1933	30.1	71.1	74.3	58.5
	1934	30.7	75.2	84.3	63.4
	1936	9.9	77.5	83.3	56.7
Mean		35.9	73.1	73.1	60.6

Table 5 includes the means of quadruplicate germinations of seed of each of the four varieties after storage at different conditions at room temperature, and is presented to give some idea of the differences among the four varieties and stocks studied.

TABLE 5.—*Percentage germination of 4 stocks of onion seed after storage for 1 to 4 years under different conditions at room temperature* [1]

SEED STORED IN NONSEALED CONTAINERS

Moisture content of seed (percent)	Year of germination	Red Bermuda	Yellow Bermuda	Yellow Globe	Valencia	Mean
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	1930	52.5	58.0	66.8	78.0	63.8
	1932	45.5	44.3	63.5	60.5	53.4
	1933	45.5	58.0	71.0	57.3	57.9
Mean		47.8	53.4	67.1	65.3	58.4
8	1930	70.5	57.8	66.8	75.5	67.6
	1932	45.5	47.8	73.8	57.3	56.1
	1933	31.8	45.3	65.0	68.8	52.7
Mean		49.3	50.3	68.5	67.2	58.8
10	1930	63.5	58.8	79.0	71.8	68.3
	1932	43.8	38.5	59.0	57.5	49.7
	1933	29.8	41.8	54.0	53.5	44.8
Mean		45.7	46.3	64.0	60.9	54.2
Mean	1930	62.2	58.2	70.8	75.1	66.6
	1932	44.9	43.5	65.4	58.4	53.1
	1933	35.7	48.3	63.3	59.8	51.8
Mean		47.6	50.0	66.5	64.4	57.1

SEED STORED IN SEALED CONTAINERS

Moisture content of seed (percent)	Year of germination	Red Bermuda	Yellow Bermuda	Yellow Globe	Valencia	Mean
6	1930	51.3	47.3	63.5	72.5	58.6
	1932	59.0	46.8	67.8	60.8	58.6
	1933	57.3	68.3	79.5	68.3	68.3
Mean		55.8	54.1	70.4	67.2	61.8
8	1930	63.8	61.8	66.3	75.8	66.9
	1932	58.5	49.8	66.5	65.3	60.0
	1933	41.3	40.3	66.0	61.5	52.3
Mean		54.5	50.6	66.3	67.5	59.7
10	1930	47.8	57.8	62.5	65.0	58.2
	1932	38.3	34.3	47.3	10.8	32.6
	1933	7.8	21.8	0	2.0	7.9
Mean		31.4	38.1	36.6	25.9	32.9
Mean	1930	54.2	55.6	64.1	71.1	61.2
	1932	51.9	43.6	60.5	45.6	50.4
	1933	35.4	43.4	48.5	43.9	42.8
Mean		47.2	47.5	57.7	53.5	51.5

[1] Difference required for significance between means of quadruplicate observations, 17.1 percent; between means involving 12 observations, 9.9 percent; 16 observations, 8.5 percent; 36 observations, 5.7 percent; 48 observations, 4.9 percent; 108 observations, 3.3 percent; 144 observations, 2.9 percent.

Tables 1 to 4 are each prepared so as to clearly show the effect of (1) temperature, (2) seed moisture, and (3) access to or exclusion of air, upon longevity of seed. Table 5 shows the effects of (1) moisture and (2) access to or exclusion of air upon longevity of each of four varieties at room temperature alone.

Table 6 sets forth, in two parts, the results of analysis of variance of the total data. In the first part, seeds adjusted to 6-, 8-, and 10-percent moisture contents and stored up to 4 years are involved. The second part includes the data for only the 8- and 10-percent moisture lots up to the seventh year of storage. Unless otherwise indicated, all variances are significant with reference to remainder error by odds

of more than 99:1. The supply of seeds of 6-percent moisture was exhausted after 4 years.

TABLE 6.—*Analysis of variance of onion-seed germination data*

Source of variation	For all onion-seed lots stored up to 4 years		For all lots of 8- and 10-percent moisture stored up to 7 years	
	Degrees of freedom	Mean square [1]	Degrees of freedom	Mean square [1]
Total	863	348.1	959	632.7
Between varieties	3	10,047.3	3	13,414.6
Between temperatures	2	8,845.2	2	81,306.5
Between moisture contents	2	5,017.4	1	16,566.8
Between years	2	14,744.4	4	8,198.9
Between replicates	3	896.3	3	378.9
Sealed versus not sealed	1	6,795.1	1	12,456.0
Varieties×temperatures	6	[2] 355.1	6	495.2
Varieties×moistures	6	[3] 293.6	3	6,772.4
Varieties×years	6	644.0	12	520.4
Varieties×sealing	3	[3] 378.1	3	4,043.3
Temperatures×moistures	4	2,084.6	2	5,625.0
Temperatures×sealing	2	7,760.4	2	10,141.5
Temperatures×years	4	3,380.9	8	16,313.2
Moistures×years	4	1,151.1	4	659.0
Moistures×sealing	2	[3] 413.9	1	2,319.8
Years×sealing	2	[3] 179.5	4	944.7
Moistures×years×sealing	4	[2] 441.3	4	386.7
Moistures×years×temperatures	8	1,240.1	8	798.1
Years×sealing×temperatures	4	[2] 349.5	8	605.6
Moistures×sealing×temperatures	4	2,690.0	2	7,083.6
Moistures×years×sealing×temperatures	8	[2] 352.6	8	571.6
Remainder (error)	783	146.6	870	111.6

[1] Unless otherwise indicated, variances are highly significant with reference to error.
[2] Significant with reference to remainder error; odds greater than 19:1, but less than 99:1.
[3] Not significant with reference to remainder error.

The effect of any one factor upon longevity in most instances is rather highly dependent upon one or more other factors. Thus, in discussing germination results due to a single factor, such as storage temperature, or seed moisture, we can speak in only very general terms and with reservations. This must be kept in mind throughout these pages.

EFFECT OF TEMPERATURE

Seeds of farm and garden crops are generally stored in warehouses that are thoroughly proof against rain or snow, but which are subject to the temperature and atmospheric-humidity fluctuations characteristic of the locality. The seeds stored at room temperature in this study were under conditions hardly representative of a warehouse, even in a southern location, since the humidity was rather low in the building during the period that the heat was on for 7 to 8 months of the year. The temperature was much higher during the winter than would prevail in an unheated warehouse in the middle and northern parts of the country. It would thus seem that "room" temperature here represents a more or less hypothetical warehouse temperature condition intermediate between those known to be quite adverse in the South and rather favorable in the North.

The 40° F. cold-storage room with a relative humidity of about 85 percent is typical of a large part of the commercial cold-storage space devoted to semiperishable products that do not require or will not tolerate freezing. The maintenance of a temperature of 40° is, of

course, much less costly than maintaining 20°, requiring less expensive equipment and less power.

Before studying the details of tables 1 to 4 with reference to effect of temperature, note in table 6 that there is a highly significant variance due to temperature.

Table 1 shows that the mean values of the unsealed lots held at 40° F. were significantly superior to those from room or 20° storage for the 4-year period as a whole, and in 1930. In 1932 and 1933, however, the seeds in nonsealed containers from all temperatures showed a low germination around 40 to 50 percent with no statistically significant differences among them. In the case of the seeds in sealed containers the 40° storage was not significantly better than the 20°, but both of these were much superior to room temperature.

Tables 1 and 2, which present data for a single variety, show some rather wide and erratic variations that can hardly be accounted for except on the basis of uncontrolled factors in the germination tests. Tables 3 and 4, containing the combined results of four varieties, show smoother trends and more consistent and significant differences. The mean results of four varieties as well as for the variety Red Bermuda alone, show 40° F. to be statistically superior to room and 20° storage of unsealed seed, and to room storage of sealed seed, for both the 4- and the 7-year periods as a whole. In considering accumulative end effects of the long storage periods at the fourth and seventh years, instead of the mean effects for all years, the superiority of cold storage is infinitely more striking. Although 20° appears significantly inferior to 40° for the first 3 to 4 years, the situation is reversed in the fifth and seventh years. The interactions between temperatures and years shown in table 6 are highly significant with reference to error, indicating a significant difference in response to temperature as time goes on. Note that germinability falls off much faster at room temperature than in cold storage, and faster at 40° than 20°.

The apparent increase in vigor of seed held at 20° F. for more than 4 years, relative to that held at 40° is difficult to explain. It is conceivable that very cold temperatures continuously held for months and years may have induced a condition of lower germinability from which the seed emerged in 5 to 7 years to exhibit a germinating power higher than that of the 40° lots.

The germination of 5- and 7-year-old seed from sealed 20° F. storage was surprisingly high. It had apparently undergone no deterioration, while the comparable material from 40° was still very good. One can hardly conclude that the 40° storage lots had improved in germinability on an absolute basis, because it is much more probable that the low figures prior to 1934 were largely the result of adverse germination test conditions. It would be safer to say that no very serious deterioration occurred over the 7 years at 40°.

EFFECT OF MOISTURE

It is unfortunate that moisture content was not determined for each lot of seed at the time it was planted each year, to obtain additional data of value in explaining the results of these studies. Moisture determinations were made, however, in the summer of 1937 on the 8- and 10-percent lots, with the following findings: The 10-percent lots stored not sealed at any one temperature had but little more moisture than the 8-percent lots, and were higher than originally

prepared regardless of the prevailing humidity of the place of storage. For the room, 40°, and 20° F. lots, originally at 8-percent moisture, these were, respectively, 9.0, 10.8, and 13.0 percent; the 10-percent group showed 9.9, 10.9, and 13.2. The sealed lots had changed less, the original 8- and 10-percent lots stored at room temperature showing 7.6 and 8.3 percent, those stored at 40°, 9.1 and 10.4 percent, and those at 20° showed 10.2 and 11.1 percent, respectively. Moisture accumulations were studied with reference to dry-matter losses over the storage period of 8 years. The small number of samples available revealed no definite correlation, although the mean dry-matter losses were greater for nonsealed than sealed; greater for 10-percent original moisture than for 8-percent; and greater for room storage than for cold storage.

The relatively great loss in weight upon drying material stored at 20° F. is not explained. The low relative humidity and the low moisture-holding capacity of the air in the 20° room might be expected to result in a very slight if any increase in moisture content of seeds. Furthermore, the low temperature might be expected to so retard life processes that very little water of respiration would be evolved. The observed results are at variance with both these suppositions.

These unexplained observations are of considerable interest, and merit further study.

It might be supposed that the seeds not sealed but adjusted to 6-, 8-, and 10-percent moisture in 1929 soon changed in moisture content, approaching equilibrium with the atmospheric moisture of the room in which they were stored, in a few months. If this were true, no great differences in germination would have been expected among unsealed moisture lots. Tables 1 and 2 show no significant differences among different original moisture lots that were not sealed, either within single years or temperatures or including all years and temperatures. Comparatively small numbers and high error variance may, however, obscure the true situation if only a part of the whole mass of data are observed. Tables 3 and 4, involving means of four varieties instead of only one, show significant differences in response to original moisture of unsealed lots. There are no significant differences between 6- and 8-percent moisture unsealed (table 3), but quite significant ones appear between 8- and 10-percent for 1932, 1933, and for the entire 4 years' storage. In table 4, significant differences appear between 8- and 10-percent moisture lots, not sealed, from 1932 to 1934 and for the entire 7 years' storage. Table 6 shows highly significant variances due to moisture, which are also significantly greater than the corresponding interactions between moisture and sealing.

The occurrence of small but significant differences between lots of originally different moisture content that were not sealed, despite the possibility of their attaining a nearly uniform moisture later, is interpreted to mean that during the few months required for the 10-percent lots to lose part of the added moisture more deterioration occurred than in the 6- and 8-percent lots. This deterioration was not consistently evident in single tests. It appeared only after 3 to 4 years and even in the later years of storage the differences were inconsistent because of the influence of storage temperature. At successively lower storage temperatures the harmful effect of a temporarily high moisture content was lessened. The interaction of moisture, sealing, and temperature was highly significant (table 6).

The seeds of different moisture contents that were stored at room temperature in sealed containers, and presumably maintained at the respective levels throughout the storage period, exhibited far more striking effects of moisture than did the unsealed lots (tables 3 and 4). At the lower temperatures, however, the differences between moistures were relatively unimportant and generally insignificant within single years. Here again will be noted the remarkably good preservation of sealed seed stored at low temperature, regardless of the three moisture contents established.

Generally speaking, low moisture is more conducive to longevity than high, and especially so at room temperature.

EFFECT OF SEALING

The importance of sealing the storage containers to prevent undesirable changes in moisture content of the seed has been indicated in the preceding section. There appears, however, to be a further and equally important effect of sealing that cannot be satisfactorily explained on the basis of moisture relations.

Sealing as compared with not sealing showed highly significant differences for both the 4- and 7-year storage periods, as evident in table 6. These tables also show variances due to interaction between moisture and sealing that are not significantly different from sealing variance. Thus, the reality of a moisture effect upon the response to sealing is established. A study of tables 3 and 4 and the high variances due to interactions among moisture, sealing, and temperature indicate that much of the total of this dependence of sealing response upon moisture is contributed by material stored at room temperature. At the lower temperatures, responses to sealing are rather consistent, regardless of moisture content.

The significantly higher germinations of the sealed versus nonsealed lots stored at 40° and 20° F., regardless of moisture content, are of particular interest. The longer the seeds were stored, the lower was the germination of the nonsealed in comparison with the sealed, even for the 10-percent lots. Thus, it seems that if the temperature is low enough to prevent injury from moisture sealed in the sample, the further exclusion of air from the seed is a very distinct benefit, possibly through retarding such aging or loss of energy as may be due to oxidation. At room temperature and 10-percent moisture, however, life processes may be so stimulated that serious injury occurs, either through exhaustion of certain reserves in nonsealed seeds, or possibly intramolecular oxidation of seeds from which oxygen is excluded. Although no proved explanation of this response can be offered here, the results are quite striking, consistent, and highly significant.

After storage for 5 to 7 years at favorable temperatures (40° and 20° F.), seed sealed with a moderate to low moisture content showed a germination 15 to 20 percent (absolute basis) higher than nonsealed seed. The relative superiority of sealed over nonsealed seed was as high as 20 to 30 percent.

STOCK OR VARIETAL DIFFERENCES

In these studies only one stock each of four common varieties from different sources was studied. This offers no adequate basis for a discussion of varietal differences, but only of stock differences. If all

four varieties had been produced under certain other conditions, either greater or smaller differences might have appeared among them, depending on the adaptability of each variety to the specific conditions of production. Four stocks of a single variety might show either greater or less differences than observed here.

There is no conclusive evidence that truly varietal differences in longevity exist.

Thus, the four varieties used here might as well be considered as four stocks, or four sources, as table 5 shows that, with the exception of Red Bermuda, the relative behavior of the four stocks throughout the studies corresponded roughly with the relative germinating power when first received.

The principal value of the results relating to stocks or varieties is to indicate the range in behavior that might normally be expected in a collection of commercial stocks. The difference between the poorest and the best in any one year may represent the difference between a good, profitable, commercial stand and a poor, unprofitable stand; or a poor stand versus no stand at all.

FIRST-ORDER INTERACTIONS

A few interaction effects have already been mentioned in the sections dealing with temperature, moisture, and sealing; namely, temperature × moisture, temperature × sealing, moisture × sealing, and moisture × sealing × temperature. Several others are of considerable interest but mention of them has been deferred to this point to avoid complicating the discussion of the principal accumulative effects of temperature, moisture, sealing, and varieties over the long storage period.

In the second part of table 6, every interaction shown is highly significant (odds more than 99:1) with reference to remainder error, but in the first part, four interactions are not significant. These are (1) varieties × moistures, (2) varieties × sealing, (3) moistures × sealing, and (4) years × sealing. The lack of significance of these interaction variances for the 4-year storage period simply means that the two factors shown for each combination were each without any effect upon the response produced by the other. This was not true when the storage period was extended to 7 years, despite the fact that one of the three original moisture conditions was dropped.

For the 7 years' storage some of the varieties showed differences in germination in response to moisture that were unlike the moisture response of other varieties; stated conversely, varietal differences for certain moisture conditions were unlike those prevailing within other moisture conditions. Similar statements may be made for the relationships of varieties × sealing, moistures × sealing, and years × sealing.

It should further be noted that of these four interactions, only the one between years × sealing is significantly different from either of the single factors entering into the interaction. Thus, years (age) produces a generally consistent harmful effect that significantly overshadows any influence of sealing, even though sealing may produce some small significant differences in response to age. Likewise, sealing produces a generally beneficial effect that may be observed in seeds of all ages, although, of course, germination of both sealed and unsealed lots tends to decrease with time.

The variances for interaction of varieties × moisture, although significant with reference to remainder error, are in no case significantly different from either of the respective single factors involved. These facts mean that for a long period of storage under all conditions of this study the extent of the effect of moisture cannot be accurately predicted without first knowing the potentialities of the material to be stored; or conversely, the relative longevity among a number of stocks may depend on the moisture they contain under the several other conditions of storage. A similar interpretation is suggested with reference to the simple and interaction effects of varieties and sealing and moistures and sealing. These variations in response to specific factors, however, became evident only after prolonged storage.

In the section on temperature, it was pointed out that differences in germinating power among the three temperature lots became more and more striking in successive years. This is easily observed in tables 1 to 4. Stated in statistical terms, there is a high interaction between temperature and years. Table 6 shows variances for this interaction that are infinitely significant with reference to remainder error. For neither the 4-year nor the 7-year period were the variances due to temperature alone or years alone significantly greater than interaction of temperature × years. Thus, for either storage period it is not possible to generalize on the effect of age without taking temperature into consideration. For the 7-year storage, variance due to temperature alone is significantly larger than that due to years alone, and interaction between temperature and years is numerically but not significantly greater than that for years alone. Thus, the preponderant effect of temperature is emphasized statistically.

The variances for the interactions, varieties × temperatures, varieties × years, and moistures × years, shown in table 6, are all significant with reference to remainder error.

Variances for varieties alone and temperatures alone for both the 4- and 7-year storage periods are quite significantly greater than interaction of varieties × temperatures. This shows that although each factor has some influence on the effect produced by the other, these respective effects are small and that all varieties respond to temperature in the same general way.

The interactions of varieties × years are of about the same magnitude as those of moistures × years; furthermore, they bear a roughly similar relation to their respective component single factor variances. Therefore, the same comments and conclusions apply as for the factors discussed in the preceding paragraph.

The variance for interaction of moistures × years during the 4-year storage period was relatively high and not significantly different from variance due to moisture alone. This high interdependence of moisture and time is easily observed in tables 1 and 3, particularly for the material stored at room temperature. The harmful effect of moisture is thus statistically demonstrated to depend largely on the time factor, even within a 4-year test. On the other hand, variance due to years alone is significantly greater than that due to moisture × years, showing that age is the dominant factor and produces the same general effect on seeds of all three moisture contents studied.

For the 7-year period (table 6) the results involving moisture and years are different from those shown for the 4-year period. It should be recalled that only the 8- and 10-percent moisture lots were involved

in the latter case, omitting the 6-percent. This may have been a minor cause of obtaining different statistical results, but only a minor cause, for tables 1 and 3 show that, in general, the responses of the 6- and 8-percent lots were much more nearly alike than were the 8- and 10-percent lots. It would seem that the low interaction value of moisture × years—significantly different from both moisture alone and years alone—was mainly due to the fact that at room temperature both moisture lots had deteriorated to a very low level after 5 years, so that there was almost no leeway for appreciable difference between moistures. At the low temperatures, as previously pointed out, germination remained high and moisture was without very marked effect.

SECOND-ORDER INTERACTIONS

All second-order interactions shown in table 6 are significant with reference to remainder error.

The interactions of moisture × sealing × temperature are of particular interest, not only because of the implications involved in the items themselves but also because of their magnitude and infinite significance with reference to remainder error. These high interaction variances mean that the effects of moisture, of temperature, and of sealing alone are individually influenced to a marked degree by the other two together. These variances for interaction for both the 4- and 7-year data are so large that they are statistically unsurpassed in magnitude by any of the first-order interactions involving the same factors. For example, this in turn means that the effect of interaction or interdependence of moisture and sealing cannot be accurately predicted as affecting longevity, without considering temperature; or that the definite effect of initial moisture and storage temperature is uncertain unless it is known whether the seed is in sealed containers.

The reader should perhaps be reminded that in consideration of interactions in which the factor for years is absent, a total effect or mean effect over the entire 4- or 7-year storage is involved, and not just responses to different treatments within a single year at any definite point in the storage period. To determine the existence of differences in response to various factors in relation to time, reference should be made to the interactions involving years. It will be noted that all are significant with reference to remainder error, although the magnitudes of the variances are relatively small. Thus, it is established that, in general, the results of the interplay of certain combinations of two factors tend to become significantly altered with the passage of time.

THIRD-ORDER INTERACTION

The items next to the last in both parts of table 6 represent the relative magnitude of the interaction of moisture content of seed × time (years) × sealing × storage temperature. In both tables the interactions are significant with reference to remainder error, showing that the interplay of all four of these factors together is of importance. Although significant with reference to remainder error, these interactions are small, and they are greatly exceeded by the variances due to the respective single factors involved, by many of those due to first-order interactions, and by some due to second-order interactions. An unjustifiable amount of space would be required here to

discuss all these relationships in detail.[3] It will suffice to emphasize here that the variance due to the interaction of the four factors mentioned is of a magnitude that indicates the importance of properly controlling every one of them if the best preservation of seed viability is to be obtained, and that the response of the seed to each storage factor or condition depends to a significant degree on the others.

SUMMARY AND CONCLUSIONS

Four stocks (different varieties) of onion seed grown in 1929 were dried at 30° to 35° C. to a uniform moisture content of 6 percent. Seeds were placed in test tubes and stored at room temperature and at constant temperatures of 40° and 20° F., sealed and not sealed. In addition to the seeds of 6-percent moisture, lots were adjusted to 8 percent and 10 percent of moisture before placing in storage.

The moisture content of the seed when received in December 1929 was approximately 7.5 percent, and the mean germination of the four stocks was 85.8 percent, as determined by the laboratory method. The seeds of the several varieties and treatments were placed in storage in December 1929.

Germination tests of the stored seeds were made in quadruplicate at intervals of 1 to 2 years in soil in the greenhouse. Germination counts were based only on sprouts that emerged from the soil. Tests were run in 1930, 1932, and 1933 on all lots of seed previously adjusted to 6-, 8-, and 10-percent moisture. In 1934 and 1936, tests on all lots adjusted to 8- and 10-percent moisture were run.

The germination data were analyzed by Snedecor's (*6*) modification of Fisher's (*2*) method of analysis of variance.

Significant differences in germinating power were evident among the four stocks from the beginning of the study. In general, those showing the highest initial germination held up the best through the successive years' tests. Other factors being equal, it appears that initially good seed will retain a commercially good percentage of germination longer than will a stock of mediocre initial germination.

Storage of onion seed at room or "natural" temperature cannot be depended upon to retain viability of commercial value more than 2 years.

Although the evidence of this single study cannot be considered as entirely adequate proof, it appears that for storage periods up to 4 years, 40° F. is superior to 20°, but that if onion seed is to be stored sealed as long as 5 years before use, 20° is the better.

Both 40° and 20° F. were greatly superior to room temperature. Storing at 20° appeared to depress germination compared with 40° for the first 4 years.

Seeds 7 years old, stored dry in sealed containers at 20° F., showed no significant loss of vitality as compared with fresh seed.

It is important that onion seed to be stored at natural temperature shall be kept dry, preferably not over 6-percent moisture content. Lots sealed with 8- and 10-percent moisture deteriorated much faster than the 6-percent lots when stored at room temperature. If the seeds are placed in cold storage, these three different moisture levels are relatively unimportant.

[3] The investigator, student, or other reader who is interested in developing these details will doubtless have at hand either Fisher's (*2*) or Snedecor's (*6*) tables of Z or F values for determining significance of difference between variances.

Sealing dry seeds in airtight containers appears to preserve viability significantly longer than storage under similar conditions not sealed. If seeds are stored sealed with a moisture content above 8 percent, sealing may, under certain conditions, result in a more rapid deterioration through the retention of a high moisture content in the seed. The effect of sealing-in moisture of seeds stored at room temperature is very disastrous, but the very dry seeds (6-percent moisture) kept better sealed than not sealed at room temperature, probably mainly because increase in moisture content was prevented.

There appears to be a benefit from sealing in addition to protection from moisture, if the seeds are stored at 40° to 20° F., a temperature low enough to prevent damage from moisture.

Germination was best preserved in these studies by sealing dry seeds and storing them at 20° F. No significant loss in germination was noted in seeds that had been so stored for nearly 7 years.[4]

Sealed seeds of 8- and 10-percent moisture stored at 40° F. appeared superior to those stored at 20° for the first 2 or 3 years, then appeared about equal, and finally were surpassed by the 20° lots.

PRACTICAL CONSIDERATIONS AND RECOMMENDATIONS

In view of the relatively high value of onion seed and the importance of high quality, it would seem entirely feasible and an economic practice to hold all stocks in cold storage if located in regions having high humidity, high temperature, or both.

Cost of cold storage space does not seem prohibitive. One large refrigeration and cold-storage firm in the eastern part of the country quoted (in 1937) the following rates on seed storage at a temperature of 34° to 36° F.: In carlots, 21 cents per hundredweight for the first month and 15 cents per hundredweight per month thereafter. In less than carlots, the rate was 5 cents per hundredweight higher per month.

With these prices as a basis for estimate, large producers or handlers of onion seed could hold large quantities at a storage cost of less than 2 cents per pound per year; and this is not all added cost over common storage, for storage in any warehouse commands some charge for space. Local dealers and large growers handling less than carlots should be able to meet their short, partial-season requirements at not over ½ to 1 cent per pound. Since it is known that onion seed deteriorates so very rapidly in warm, humid areas, as in the Gulf region, it would seem wise to have incoming shipments made direct to cold-storage warehouses, from which seed could be withdrawn as needed for planting or retail sale. Large planters are sometimes prevented from planting the acreage for which seed is on hand. Without cold storage, hundreds of pounds of seed may be a complete loss; with it, good seed can be kept safely until the following season, with very little if any required increase in rate of planting to compensate for loss of viability.

The importance of low-moisture content of seed suggests the practicability of using "moistureproof" bags for shipping and handling, such as are used for certain hygroscopic chemicals. It should be emphasized again, however, that if moistureproof containers of any kind are used, the seeds must be dry, preferably containing not over

[4] Since these results were prepared for publication, further germination tests made in 1938 still show no apparent loss in germinating power when so stored.

6-percent moisture before being bagged. This work further suggests the possible value of artificial drying equipment for reducing moisture content of seed at a mild temperature, before placing in moistureproof or moisture-resistant containers.

If cold storage is not available, thorough drying to 6-percent moisture or less and preservation of dryness will be of value, but evidently of much less value than low temperature in preserving the vitality of the seed. Even though cold storage is available, it is important that the moisture content of the seed be kept low to prevent deterioration before or after storage.

If it is desired to keep portions of valuable breeding stocks or experimental materials for several years, they should be thoroughly dried, sealed in glass or metal containers, and stored at a temperature near 32° F. or somewhat lower.

If difficulty is encountered in maintaining a low moisture content of seed, low-temperature storage becomes the more imperative. Commercial cold storage at 34° to 36° F. will probably be most readily available and would appear to be entirely satisfactory—possibly more desirable than either 40° or 20°.

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